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Potential Of Using Rainwater for Potable Purpose in Malaysia with Varying Antecedent Dry Intervals

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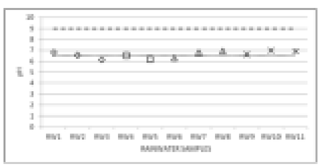
Graphical abstract



Abstract

Water rationing and abrupt disruption of water supply which directly affects the consumer daily activities were caused by the shortage of raw water to the treatment plant. Rainwater where Malaysia received more than 3000 mm per year is an attractive alternative water resource for clean treated water. Furthermore, it is always considered that rainwater is of high quality and with minimum treatment can be served for potable uses. This study investigates the quality of harvested rainwater over varying Antecedent Dry Intervals (ADI) from one, two, three and more than nine days. Samples were analysed for parameters of pH, DO, BOD_5, COD, TSS, NH_3-N and E. Coli. Analysis was made to compare with the drinking standards set by the Ministry of Health, Malaysia (MOH), the Department of Environment, Malaysia (DOE) and World Health Organisation (WHO). Measured pH and DO did not vary with ADI days and gave relatively consistent values within the standards. The concentrations of BOD_5, COD, TSS, NH_3-N and E. Coli were insignificantly changed for samples with ADI less than three days, but were increased for the rainwater samples collected after more than nine days. Even so, all samples were reasonably below the acceptable limit set by the Malaysian authorities, except for E. Coli. The three millimetres first flush for the rainwater is sufficient and with minimum treatment, the use of rainwater can be extended to potable uses.

Keywords: Rainwater harvesting, antecedent dry intervals, potable uses.

Abstrak

Pencatuan dan gangguan mendadak bekalan air yang menjejaskan aktiviti harian pengguna secara langsung berlaku akibat dari kekurangan air mentah ke loji rawatan air. Air hujan di mana Malaysia menerima lebih dari 2500 mm setiap tahun merupakan satu alternatif baik sebagai sumber air untuk rawatan air bersih. Tambahan pula, air hujan biasanya dianggap berkualiti tinggi dan dengan rawatan minimum boleh dijadikan sebagai air boleh minum. Kajian ini melihat kepada kualiti tuaian air hujan mengikut Sela Anteseden Kering (ADI) iaitu satu, dua, tiga dan lebih dari sembilan hari. Parameter pH, DO, BOD_5, COD, TSS, NH_3-N and E. Coli bagi setiap sampel tuaian air hujan dilakukan. Analisis data diperolehi dibandingkan dengan standard panduan air minum digariskan oleh Kementerian Kesihatan Malaysia (KKM), Jabatan Alam Sekitar, Malaysia (JAS) dan Organisasi Kesihatan Dunia (WHO). Parameter terukur pH dan DO tidak berubah mengikut hari ADI dan memberikan nilai konsisten mengikut garis panduan. Kepekatan parameter BOD_5, COD, TSS, NH_3-N and E. Coli tidak berubah untuk sampel ADI kurang dari tiga hari, tetapi dilihat menaik untuk sampel air hujan lebih dari Sembilan hari. Walau begitu, kesemua sampel berada di bawah had maksimum yang ditetapkan oleh badan berkuasa Malaysia, kecuali untuk parameter E.Coli. Tiga milimeter air hujan pertama sebagai curahan adalah mencukupi dan dengan rawatan minimum, air hujan tertuai boleh dilanjutkan penggunaannya sebagai air boleh minum.

Kata kunci: Tuaian air hujan, sela anteseden kering, kegunaan air boleh minum.

1.0 INTRODUCTION

Rainwater harvesting is experiencing a renaissance. Across the globe, the system is being fitted to provide a source of non-potable or potable water and serving as a method in facing the challenges of water scarcity, water stress and increasing demand of water supply. Malaysians consumed water at an average rate of 280 to 310 l/capita/day, the highest among the South East Asian neighbours [1-2]. Similar consumption rate was found even in a university campus, around 260 l/capita/day [3]. This high water utilisation affects the three pillars of sustainability i.e. to reduce water costs (economy), to reduce impact on water resources (environment) and to have a security of access to water (society). Climate change and population growth, as well as other pressures, are increasingly having an impact on water resources across the globe [4].

The sources of drinking water supply in Malaysia are coming from the surface water such as rivers, reservoirs and lakes, where the demand from these resources is a significant 97% [5]. However, deteriorating water quality from uncontrolled anthropogenic activities and decreasing quantity due to severe droughts caused disruption of treated water to consumers. Recent water rationing (from March to April 2014) in Selangor significantly affected more than seven million consumers in the Klang Valley. As an alternative to the surface water, rainwater is attractive to be utilised as raw water sources for clean water [6-7]. Furthermore, preliminary risk analysis suggested that the rainwater in general is good quality and have little contribution of pathogens to users [8].

The quality of rainwater can vary due to air pollution caused by industries and high concentration of automobile emissions [9-10]. Prior year 1998, lead was one of the major contributor pollutants in the urban atmosphere. The introduction of unleaded petrol and the Environmental Quality Regulation however has since significantly reduced the lead pollution in the air. In comparison to the Malaysian standard of allowable level of lead (1.5 µg/m3), since 1998 the level of lead in Kuala Lumpur remains less than 0.1 $\mu g/m^3$ [11]. The rainwater quality is not only dependent on the air quality of surrounding area but as the rainwater is usually collected as runoff from the rooftop, the quality may also be compromised by the type of roof and the contamination at roofs by rodents, birds and animal wastes [12].

Dimensionless Water Quality Index (WQI) is used to evaluate the status of the river water quality, where major parameters analysed are the BOD5, NH3-N and SS, DO, COD and pH. Any water falls under the range of 81-100 is considered as clean and may be used as water resource. This study attempts to investigate the rainwater quality in Bandar Baru Bangi, Selangor with the focus on varying antecedent dry interval (ADI) days. The outcome of this study will be useful for policy makers to draw conclusions about the use and required treatment of rainwater as a potential drinking water source at house hold level.

2.0 METHODOLOGY

Rainwater samples were collected from the roof of a cabin room, situated at the campus near Bandar Baru Bangi, a district in the state of Selangor, 30 km away from the capital, Kuala Lumpur. Malaysia generally receives abundant of rainfall throughout the year up to 3000 mm and the study area received a well distributed annual rainfall with the average rain of 2700 mm (MMD, 2014). The highest rainfall is experienced in October (during monsoon season) with an average of 483 mm and the driest month is January with approximately 120 mm. The structure has an area of 13x50 m^2 covered by corrugated galvanised iron sheet rooftop. This rooftop material is ideal as it provides complete wash ability of pollutants by first flush [13]. The roof is sloped on east and west sides, and no gutter exists. The first three millimetres of rainwater was discarded as first flush and is in line with the standard guideline and findings obtained from previous studies [14-17]. In total, 11 rainwater samples were collected from rain fall events in the months of February and March in the year 2014, taking into account the ADI days for each rainfall event. In the month of February, Selangor experienced quite a lengthy dry spell, where study area received very much less rain below the normal rainfall (MMD, 2014). The rainwater samples for long ADI days were obtained during this period. Coming into the first 10 days of March, the study area had rainfall amount between 10 to 30 mm. The consequent days of March, however showed an increase of rainfall to 70-100 mm and the rainwater samples for lesser ADI days were collected during this period.

The samples were analysed for seven parameters: pH, dissolved oxygen (DO), biochemical oxygen demand (BOD^5), chemical oxygen demand (COD), Ammonia-Nitrogen (NH^3-N), total suspended solids (TSS) and bacteria E. coli. The analysis of pH, DO, COD, NH^3-N and TSS were immediately determined within 24 hours after sampling. After determining DO in the samples, BOD bottles were preserved in incubator at 20^0C and after five days remaining DO was measured. From these BOD^5 was calculated.

Table 1 Standard methods and instruments used for testing different parameters

Parameter	Standard Method	Instrument used
pH	Geotechnical Test Method, GTM-24, Revision #2	EUTECH Cyberscan pH 300 Singapore
DO	Standard Dilution Method 8043	YSI Model 5000-230V Dissolved Oxygen Meter USA
BOD_5	Standard Dilution Method 8043	YSI Model 5000-230V Dissolved Oxygen Meter USA
COD	USEPA Reactor Digestion Method 8000 for low range COD	Hach brand DR 6000 spectrophotometer
TSS	Photometric Method 8006	Hach brand DR 6000 spectrophotometer
NH_3-N	low range Salicylate Test Powder Pillows method 8155 (Hach, Loveland, CO, USA)	Hach brand DR 6000 spectrophotometer
E. Coli	Association of Analytical Communities (AOAC) Official Method 991.14	3M Petrifilm™ E.coli/Coliform Count Plate (3M, St. Paul, MN, USA)

The instruments used were EUTECH Cyberscan pH 300 Singapore for pH, YSI Model 5000-230V Dissolved Oxygen Meter USA for DO and BOD5, Hach brand DR 6000 spectrophotometer for COD, TSS and NH3-N. Number of E. coli was determined by plating 1 ml of sample water on 3M Petrifilm™ E.coli/Coliform Count Plate (3M, St. Paul, MN, USA). E. coli were counted after 48 hours incubation at 36^0C. COD was analysed with the USEPA Reactor Digestion Method 8000 for low range COD, while N-NH^3 concentrations were determined photo metrically by the low range Salicylate Test Powder Pillows method 8155 (Hach, Loveland, CO, USA). BOD^5 and TSS were determined by Standard Dilution Method 8043 and Photometric Method 8006, respectively.

The measured values of the parameters were compared with the drinking standard guideline of three agencies i.e. the Ministry of Health, Malaysia (MOH) [19], the Department of Environment, Malaysia (DOE) [20] and the World Health Organisation (WHO) [21].

3.0 RESULTS AND DISCUSSION

The study area is within the vicinity of reserve forest, has low traffic intensity and is about five kilometres away from the nearest industrial zones. As such, hypothetically, it is expected that the harvested rainwater is of good quality. The analysed rainwater samples provide background on the overall quality of the rainwater on site, here shown in Table 2. Three samples were obtained after one day of ADI, two and three samples for two and three days of ADI, respectively and three samples were collected after 10, 11 and 15 days each, from the previous rain event. For simpler representation, the samples were categorised according to the ADI days, where three samples of ADI > 9 days were grouped together.

Table 2 Value of different water quality parameters in rainwater

Sample No	ADI (day)	pH	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TSS (mg/l)	NH_3-N (mg/l)	E. Coli (no/ml)
RW1	1	6.80	8.49	0.68	0	0	0.30	0
RW2	1	6.55	8.64	1.58	0	1	0.07	0
RW3	1	6.15	8.58	1.90	0	1	0.25	0
RW4	2	6.52	8.18	1.96	0	4	0.11	1
RW5	2	6.18	8.55	1.73	0	1	0.24	0
RW6	3	6.32	8.46	1.76	0	1	0.23	0
RW7	3	6.79	8.33	1.84	0	0	0.05	0
RW8	3	6.92	8.77	1.54	0	3	0	2
RW9	10	6.63	8.25	2.45	0	8	0.81	3
RW10	11	6.98	8.76	2.77	0	11	0.70	9
RW11	15	6.90	8.78	2.58	0	9	0.80	4

The discussion starts with the analysis of COD as data shows zero values in all the rainwater samples. The COD was not detected and is believed due to the lower concentrations than the quantification limits. Interestingly, the varying ADI days also did not increase the COD values where analysis shows undetected measurement. This echoes the findings that the concentration of COD is always negligible in the monsoonal region and away from the coast [22, 23]. The DOE prescribed value of COD is less than 10 mg/l (DOE, 1985) but MOH and WHO did not provide guideline value of COD. Rönkä [24] reported that drinking water supply should not exceed COD of 2.5 mg/l and potable water of COD content greater than 7.5 mg/l is regarded as poor.

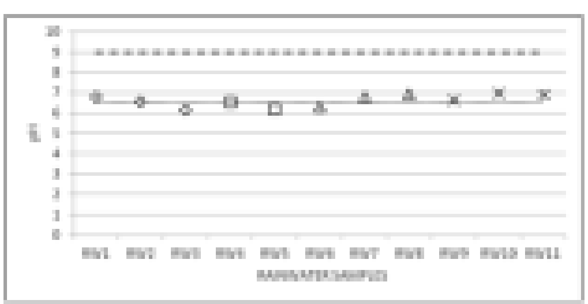


Fig 1 pH values for harvested rainwater for ADI of 1 day (◇), 2 days (□), 3 days (△) and more than 9 days (X). Dotted and dashed lines represent the acceptable range set by MOH (6.5 to 9.0).

The obtained pH values are plotted in Fig. 1 along with the maximum and minimum limit set by Malaysian authorities. The MOH suggested the acceptable range of pH to be 6.5-9.0 whereas the DOE prescribed value of pH to be more than 7 [20]. Data shows that all samples are within the acceptable limit except for samples RW 3, 5 and 6, although all values are closely to the lower limit. Even so, according to Leo and Dekkar [25], it is suggested that rainwater pH range 5.5-6 may not be harmful for consumption. The ADI days do not have any significant impact on the pH value of the harvested rainwater.

The concentration of DO for all rainwater samples is presented in Fig. 2. The lower limit plotted here is taken as suggested by MOH, that is the acceptable level of DO to be 7 mg/l (MOH, 2000). Note that the value also coincides with DOE, where the prescribed value of DO should be more than 7 (DOE, 1985). Data shows that all samples are within the range of 8.1 – 9 and fall well above the recommendation limit. Previous studies of Avvannavar and Shrihari [26] suggested the optimum value for good water quality is between 4 to 6 mg/l of DO, and Cruise and Miller [27] prescribed threshold for DO is 5.0 mg/L for drinking water. As such, the harvested rainwater is of high quality according to guideline set by the WHO and even can be categorized suitable as drinking water.

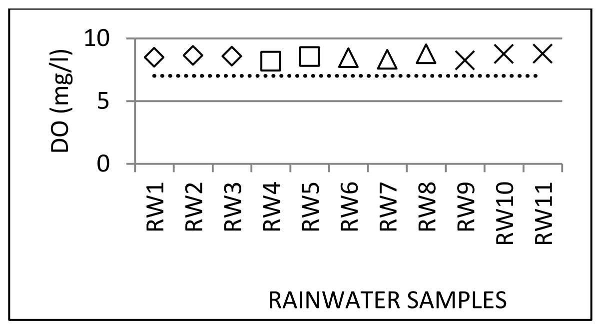


Fig 2 Measured DO values for harvested rainwater for ADI of 1 day (◇), 2 days (□), 3 days (△) and more than 9 days (X). Dotted line represents the minimum acceptable level set by MOH (7 mg/l).

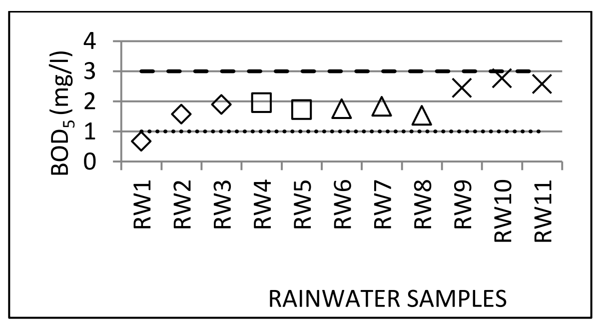


Fig 3 Measured BOD^5 values for harvested rainwater for ADI of 1 day (◇), 2 days (□), 3 days (△) and more than 9 days (X). Dotted and dashed lines represent the standards given by DOE (1 mg/l) and the EC (3 mg/l), respectively.

The analysis of BOD^5 for the different rainwater samples are presented in Fig. 3. The DOE prescribed value of BOD^5 is less than 1mg/l but MOH and WHO imposed no health based guideline value of BOD^5 [19,21]. The Environment Canada (EC), [28] reported that drinking water sources should have BOD^5 less than 3 mg/l and water with BOD^5 less than 4 mg/l is of good quality. All samples except for RW1 are well above the allowable limit set by the DOE but fall as good quality according to the EC guideline. As the concentration of BOD^5 is interrelated with DO, MacDonald et al., [29] suggested that the biochemical oxygen demand should not be so great as to lower the dissolved oxygen to an unacceptable level (6.0 mg/l or less) and De [30] opined to maintain minimum 2 to 7 mg/l of DO level in water for the degradation of oxidizable organic matter. The longer ADI obviously has affected the BOD^5 concentration, where the values consistently increased while ADI > 9 days.

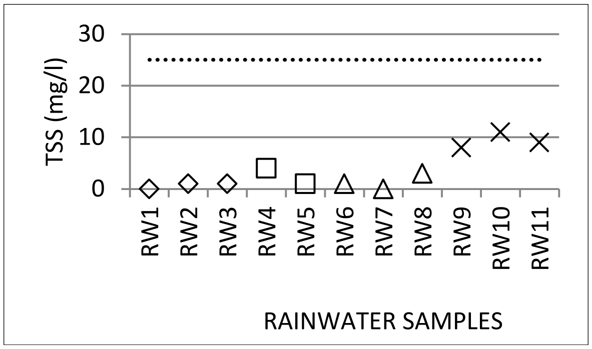


Fig 4 Measured TSS values for harvested rainwater for ADI of 1 day (◇), 2 days (□), 3 days (△) and more than 9 days (X). Dotted line represents the standards given by DOE (25 mg/l).

Analysis of TSS for all rainwater samples are presented in Fig. 4 and the limit is taken as 25 mg/l as set by the DOE. The measured TSS ranges from 0 to 9 mg/l, where all samples were well below the maximum limit. Not only this indicate that the three millimetres first flush is sufficient but also confirmed the hypothesis of high quality of rainwater in the study area. It is noted that rainwater collected after longer ADI (> 10 days) has higher concentration of TSS. Even so, for such dry spell duration, the 3 mm first flush is sufficient and produced good quality water.

Ammonia-Nitrogen (NH^3-N) in the harvested rainwater samples are presented in Fig. 5 and the allowable limit of 1.5 mg/l and 0.1 mg/l as set by the MOH and DOE, respectively is shown. The obtained value ranges from 0 to 0.8 mg/l. For rainwater samples collected at ADI of one, two and three days, there were no obvious differences in the concentration values. However, increasing ADI days increased the NH^3-N concentration up to threefold. Even so, all samples were well below the MOH standard value. Note that only four samples (ADI < 4 days) were found to comply with the DOE standard.

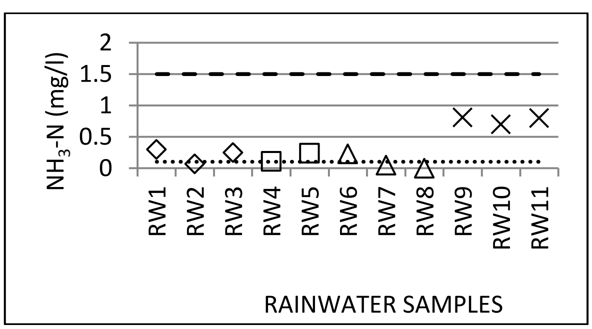


Fig 5 Measured NH3-N concentration for harvested rainwater for ADI of 1 day (◇), 2 days (□), 3 days (△) and more than 9 days (X). Dotted and dashed lines represent the standards of DOE (0.1 mg/l) and MOH (1.5 mg/l) respectively.

The presence of E. Coli in the rainwater samples is shown in Fig. 6. Both MOH and DOE prescribed that there should not be any E. Coli present in drinking water [19, 20]. Rainwater samples collected at ADI one day show no presence of E. Coli. In the samples collected at ADI two and three days has low concentration of E. Coli, even some samples shows no presence of E. Coli at all. The low presence of E. Coli is believed to be contributed by the sufficient flushing of the animal wastes. For ADI > 9 days, however, longer dry spell duration gives ample times for the accumulation of animal waste on the rooftop. Samples evidently show the existence of E. Coli ranging 2-9/ml of sample. Three millimetres of first flush is inadequate to remove the dehydrated animal wastes. The data obtained has similar findings with the previous research, where the rainwater collected showed negative presence of E. coli as well as a very low concentration of E. coli [13, 31].

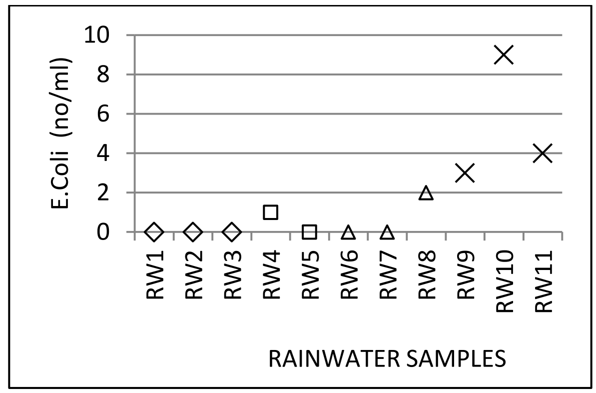


Fig 6 The presence of E. Coli in the harvested rainwater samples for ADI of 1 day (◇), 2 days (□), 3 days (△) and more than 9 days (X). According to all standards, the number of E. Coli in the sample must be zero.

Analysis indicates that the harvested rainwater on campus in general has good quality. It can be immediately used for non-potable uses such as toilet flushing or gardening. Proper rainwater storage needs to be employed as uncontrolled storage deteriorates the water quality. This was shown by the previous study, where samples at the rainwater collection tank (at the same campus) had higher pH, BOD^5, NH^3-N and E. Coli [32]. High temperature promotes the microbiological activity, increasing the concentration of BOD^5 and high presence of E. Coli. The microbiological and chemical quality of tank-stored rainwater is impacted directly by roof catchment and subsequent run-off contamination, via direct depositions from birds and small mammals, decay of accumulated organic debris, and atmospheric deposition of airborne micro-organisms and chemical pollutants.

■4.0. CONCLUSIONS

This study investigates the reliability of the harvested rainwater in Selangor as water resource. Samples of rainwater were collected directly from a rooftop were analysed for seven common physical and chemical water parameters of pH, DO, TSS, BOD^5, COD, NH^3-N and E. Coli. Of the six parameters analysed from the samples, only the presence of E. Coli hinders the utilisation of rainwater for potable uses. All samples show that parameters pH, DO, TSS and NH^3-N adhered to the drinking water standards set by the Malaysian authorities. Although the parameter BOD^5 did not comply with the DOE standard, where measured values were above the maximum limit, the concentration obtained was still within the range permitted by the Canadian drinking water guideline. The antecedent dry interval between one to three days has relatively insignificant impact on the parameter values. Increasing the interval days to more than 10 days, however, gave an increment of concentrations for parameters BOD^5, TSS, NH^3-N and E. Coli. No significant changes however were observed for pH and oxygen concentration in the harvested rainwater for varying antecedent dry interval days.

Events of the recent water rationing promoted the realisation of harvesting rainwater as the alternative water resource for treated water. Analysis shows that with simple treatment and disinfection, utility of rainwater in Malaysia can be extended to potable uses from its current non-potable uses.

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